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(54) Nuclear camera systems.

(57) A nuclear camera system, e.g. for medical diagnostic imaging, comprises a plurality of radiation detector heads (10a, 10b, 10c) mounted on a rotatable portion (16) of a gantry (18). A transmission radiation source and collimator assembly (40, 42) is mounted on the rotatable gantry portion opposite one of the detector heads. The radiation source (60) of the assembly is mounted in a lead shield (62) with an opening (64) pointing toward an examination region (12). A shutter (66) is rotatable between a closed position in which a lead arc segment (70) blocks the opening (64), a calibration orientation in which tin (72) covers opening (64), and an open position in which an opening (74) is aligned with the opening (64). A safety interlock means (80) locks the shutter in the closed position and against rotation when the radiation source and collimator assembly is removed from the rotatable gantry portion. The collimator (42) has lead side walls (200) and tin or tin alloy septa (202). When the radiation from the radiation source strikes the lead side walls, they emit characteristic lead x-rays of about 88 keV whereas the tin radiates x-rays of only about 30 keV. A filter (210) includes an inner layer (212) of tin for attenuating any remaining 88 keV lead x-rays coming from the transmission line source assembly and converting them to about 30 keV radiation. The filter has an outer lay r (214) for attenuating the radiation around 30 keV.

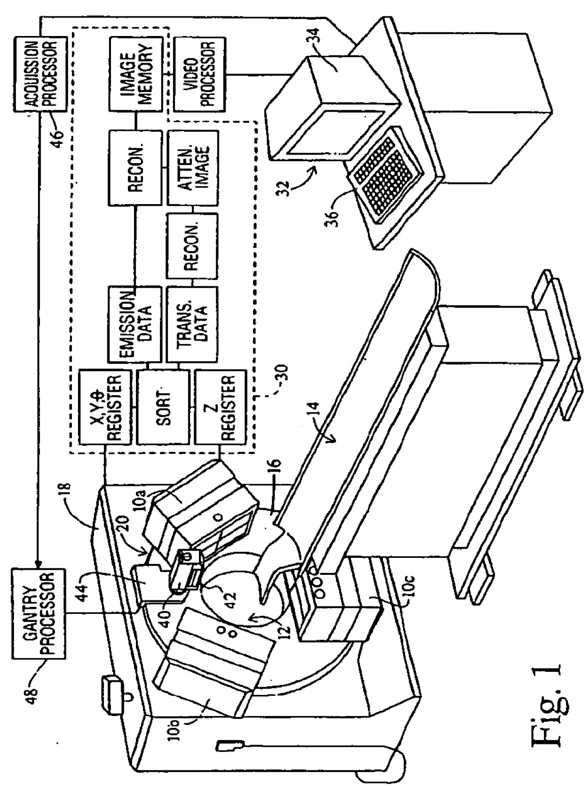

Fig. 1

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The present invention relates to nuclear camera systems, such as are used for medical diagnostic imaging. It finds especial application in conjunction with single-photon emission computed tomography (SPECT) camera systems that include one or more transmission radiation line sources and will be described with particular reference thereto. It is to be appreciated, however, that the invention will also find application in conjunction with other types of nuclear camera system.

Heretofore, single photon emission computed tomography has been used to study the radionuclei distribution in subjects. Typically, one or more radiopharmaceuticals were injected into a patient's blood stream for imaging the circulatory system or specific organs which absorb the injected radiopharmaceuticals. One or more gamma or scintillation camera heads were placed closely adjacent to a surface of the patient to monitor and record radiation emitted by the radiopharmaceuticals. In single photon emission computed tomography, the heads were rotated or indexed around the subject to monitor the emitted radiation from a multiplicity of directions. The data monitored from the multiplicity of directions was reconstructed into a three-dimensional image representation of the radiopharmaceutical distribution within the patient.

One of the problems with the SPECT imaging technique is that the patient is not completely homogeneous in terms of radiation attenuation or scatter. Rather, the human patient includes many different tissue and bone types which absorb or scatter radiation from the radiopharmaceuticals to different degrees. The SPECT images can be made more accurate if they are corrected for the radiation lost to scattering or attenuation along each path through the human torso.

As described in our U.S. Patent No. 5,210,421, a radiation line source can be positioned opposite one or more of the gamma or scintillation camera heads. Transmission radiation from the line source received by the opposite detector head can be reconstructed into a three-dimensional image representation of the radiation absorptive properties of each incremental volume element of the patient, analogous to a CT scan. This radiation attenuation information is utilized to correct the SPECT data. When the radiation line source and the radiopharmaceuticals have distinctly different energy peaks, the transmission radiation and photon emission radiation image data can be collected concurrently and separated based on energy.

In the prior art, collimators were typically constructed of lead. When lead is struck with incident radiation, such as the radiation from the line source, th lead emits an x-ray with a characteristic energy of about 88 keV. The 88 keV x-ray has an energy which is sufficiently close to the emission energy of som common radiopharmaceuticals that it is difficult to distinguish the two. This inability to distinguish reliably radiation from the radiopharmaceuticals and radiation emitted from the lead caused errors in the resultant radiopharmaceutical image.

One solution for separating the lead x-rays coming from the line source assembly from the radiation emitted from the radiopharmaceuticals was to conduct the line source transmission radiation examination first. The transmission line source was removed or closed before the radiopharmaceuticals were injected and imaged. However, performing the transmission examination and the radiopharmaceutical diagnostic examination sequentially lead to registration problems. The transmission radiation data and radiopharmaceutical images data frequently became at least partially misaligned. This misalignment caused incorrect transmission radiation based corrections on the radiopharmaceutical data causing further image degradation.

The present application provides a nuclear camera system which overcomes the above-described problem.

According to the invention there is provided a nuclear camera system which includes a transmission radiation source which allows primary radiation of a characteristic energy to be transmitted toward a subject, and a collimator for collimating the primary radiation transmitted by the radiation source, at least one of the radiation source and collimator tending to emit secondary radiation in response to incident radiation from the radiation source, characterized in that the system includes means for limiting the effect of the secondary radiation on images produced by the system.

In a preferred arrangement according to the invention the system further includes: a shutter for s - lectively allowing and preventing primary radiation from said source to be transmitted towards the subject, a connecting means for selectively connecting the radiation source, shutter, and collimator to the rest of the camera system and a safety interlock which locks the shutter in a closed position when the radiation source, shutter and collimator assembly is removed from the rest of the camera system.

The invention finds particular application where the camera system produces an image from radiation emitted by a radiopharmaceutical material injected into the subject and the transmission radiation source radiation is used to provide data for correction for radiation lost to scattering or attenuation in the subject.

The invention also provides a method of diagnostic imaging in which a subject is injected with a radiopharmaceutical having a first characteristic nergy and in which radition from a transmission radiation source having a second characteristic energy is transmitted from the transmission radiation source through a collimator, through the subject, and to a detector head, part of th radiation from the radiation

source striking int rnal surfaces of th transmission radiation source and/or collimator causing the emission of secondary radiation, characterised by: limiting the secondary radiation passing through the subject.

One camera system according to the invention and a method in accordance with the invention will now be described, by way of example, with reference to the accompanying drawings in which:-

Figure 1 is a perspective view of the camera system;

Figure 2 is an enlarged end view of a radiation source and collimator assembly of the system with a cover off a radial position adjusting mechanism;

Figure 3 is a perspective view of the radiation source and collimator assembly with a filter slid open to expose a collimator septa;

Figure 4 is a cross-sectional view through the source, shutter, and collimator of the assembly of Figures 2 and 3;

Figure 5 is an exploded view of the radiation source holder; and,

Figure 6 illustrates an interior view along section 6-6 of Figure 5.

With reference to Figure 1, the camera system includes a plurality of gamma camera heads 10a, 10b, 10c, disposed equidistant around a subject examination region 12. A patient couch or other subject support 14 selectively supports a portion of an examined subject in the examination region.

The detector heads are mounted to a rotatable gantry portion 16 which is connected to a suitable motor and bearing assembly supported by a stationary gantry portion 18 to function as a means for rotating or indexing the detector heads around the examination region. Also mounted to the rotating gantry **16** are a plurality of mechanical drives (not shown) for moving each of the gamma camera heads independently radially toward and away from the examination region. The gamma camera heads are preferably mounted on roller carriages or slide bars for smoother, easier movement. The mechanical drives for moving the gamma camera heads radially preferably each include a motor that rotates a screw drive that engages a follower mounted to the gamma camera head.

Each camera head includes a scintillation crystal that responds to incident radiation by producing a flash of light. An array of photomultiplier tubes produce electrical signals in response to each light flash. The signals responsive to the scintillations or flashes of light are combined. The magnitude z of the resultant sum is indicative of the energy of the incident radiation. Th relative response of the closest photomultiplier tubes is indicative of the spatial location x,y of the scintillation. An encoder (not shown) indicates the angular orientation θ of the receiving detector head around th examination region.

A transmission radiation source assembly **20** is also mounted on the rotating gantry portion **16**. The transmission radiation source transmits radiation across the examination region **12** to an opposit ly disposed detector head **10**c. Optionally, additional transmission radiation sources may be disposed opposite others of the detector heads.

A reconstruction processor **30** processes the electrical signals from the detector heads as the detector heads are moved around the examination region to reconstruct a three-dimensional image representation.

Detected radiation from the transmission source is separated from detected radiation from the radiopharmaceutical on the basis of the energy z of the photon peaks. The reconstruction processing means **30** processes the transmission radiation to reconstruct a three-dimensional transmission radiation image representation indicative of the transmission radiation absorptive or blocking properties of the examined region of the subject. The transmission radiation information is used to corrected the reconstructed emission radiation image representation in the injected radiopharmaceuticals. The preferred reconstruction and correction processing is illustrated in great r detail in parent U.S. Patent No. 5,210,421.

An operator control panel **32** includes a video monitor **34** for converting selected portions of th emission image representation into a human readable display. Optionally, transmission images might also be displayed. A keyboard **36** enables the operator to control the image reconstruction process, the selection of displayed data, the selection of preselected scanning procedures, and custom operation of the SPECT camera gantry. That is, the operator can control rotation of the rotatable gantry portion **16**, movement of the detector heads radially toward and away from the examination region, and positioning of the patient couch **14**.

With continuing reference to FIGURE 1 and further reference to FIGURES 2 and 3, the transmission radiation source **20** includes a transmission radiation source holder **40**, a transmission radiation source collimator **42**, and a means **44** for radially positioning the transmission radiation source. The operator through the console **32** selects a program routine from an acquisition processor **46**. The acquisition processor supplies the initial information to a programmable gantry mounted processor **48**. More specifically, a motor **50** selectively rotate a drive screw **52** that is received in a threaded drive **54** to which the radiation holder and collimator assembly is mounted. The motor **50** under control from the gantry processor **48** radially positions the transmission radiation source. For stability, the radiation source and collimator assembly are slidably mounted on a fixed rail **56** to insure accurate radial sliding movement. A spatial encoder **58** makes a precise determination of the radial position of the transmission radiation source holder and

collimator assembly. Electromechanical controls controlled through the gantry processor **48** control opening and closing of the shutter for the transmission radiation source and other functions described below.

With continuing reference to FIGURE 2 and further reference to FIGURES 4 and 5, the transmission radiation source holder **40** supports a transmission radiation source **60**, e.g. a stainless steel tube about the size of a pencil which is filled with a radioisotope. The radiation source is mounted in a lead shield **62** that has an opening **64** for directing radiation toward the examination region. A shutter assembly **66** is mounted for rotation around the radiation source. The shutter includes an aluminum cylinder or frame **70**. The aluminum cylinder supports a radiation blocking or lead circular arc segment **72** which is positioned in front of the opening **64** when the shutter is closed. The aluminum cylinder also supports a tin arc segment **74** which is aligned with the opening **64** when the collimator is rotated 90° clockwise (in FIGURE 4) to a calibration position. The shutter cylinder further includes an opening **76** which is aligned with opening **64** when the cylindrical shutter is rotated counterclockwise to the open position. The shutter is rotatable between the closed, calibrate, and open position by the electromechanical drive mounted to rotatable gantry portion **16**. A manual knob **78** located on the face of the transmission radiation source holder **40** provides a visual indication of the position of the shutter **66**.

With particular reference to FIGURES 5, and 6, in order to prevent the operator or a technician from inadvertently opening the shutter when the assembly is not attached to a scanner, a mechanical interlock system **80** is provided. More specifically, the interlock system **80** mounts the transmission radiation source and collimator assembly **40**, **42** to the radial positioning means **44** on the rotating gantry portion.

A clamping ring **84** receives a pair of mounting studs **86** from the gantry portion and rotates about 50° to twist and cam lock the assembly **40, 42** to the mounting studs. A pin **88** extends from the clamping ring through an arced aperture **90** to engage a limit switch **92** in the fully locked-on position. The switch **92**, thus, provides an electrical feedback to the control panel **32** indicating that the assembly **40, 42** has been locked into place. One or more guide pins **94** assure that the assembly **40, 42** is mounted in the proper orientation.

Once the assembly **40, 42** is locked to the gantry assembly, a shutter coupling clutch assembly **100** connects the shutter **66** with an electromechanical drive **102**. The electromechanical drive engages a shutter drive coupling **104** which is connected with an internal drive coupling **106** by a spring biased ball assembly **108**. The internal transfer coupling **106** includes a pin **110** that engag s a slot **112** in the shutter **66**. An end drive sleeve **114** has an arcuate aperture through which the pin **110** extends. The drive end sleeve **114** further has a pin **116** for engaging a slot **118** in the lead line source holder shield **62** to fix the angular orientation of opening **64**. A gantry mounted lever **120** selectively lifts the ball **108** against the spring bias decoupling the internal drive member **106** from the shutter drive member **104**. This releases the shutter such that it can be manually rotated by the knob **78**.

A lockup assembly **130** locks the shutter in the closed position with lead segment **72** across opening **64** unless the assembly **40, 42** is locked to the gantry. The lockup assembly includes a pin **132** which is slidably received in a steel sleeve **134** in the holder assembly. When the shutter **66** is in the closed position, an aperture in a steel guideway **136** in the shutter **66** is aligned with the pin **132**. The head of the pin is received in a camway **138** in a shutter locking cam ring **140** which is affixed to the clamping ring **84**. (It should be noted that in the exploded view of FIGURE 5, the clamping ring **84** is illustrated positioned on the right side of locking pin **132**. When the assembly is completed, the clamping ring **84** is in actuality on the left side of locking pin **132**. The locking pin **132** is, in this manner, received between the clamping ring **84** and the shutter locking ring cam **140**.) The cam **138** raises radially outward as the clamping ring **84** approaches its closed position to lift the locking pin **132** from the shutter **66**, releasing the shutter for rotation.

It will further be noted that in order to rotate th clamping ring **84** to remove the assembly, the cam surface **138** must be permitted to cam the locking pin **132** into the aperture in the shutter. If the shutter is not closed and the aperture is not aligned with the locking pin, then the cam **138** will be unable to cam the locking pin downward and will lock the clamping ring **84** against rotation. Hence, the mechanical interlock **80** cannot be released to remove the line source/collimator assembly **40, 42** from the gantry unless the shutter is in the closed position.

The lockup assembly **130** further includes a pin **142** mounted to the radial drive mechanism **44** fixed to the gantry. The pin extends through an aperture in member **144** to engage a locking element **146**. The pin **142** lifts the locking element **146** against the bias of a spring **148** out of a seat in member **144** permitting the clamping ring **84** and locking member **146** to be rotated. To remove the assembly from the gantry, the clamping must be rotated to the position in which (1) the pin **132** is received in guideway **136** and (2) locking element **146** is biased against pin **142**. Upon removal, the locking element **146** is seated in member **144** locking the clamping ring against rotation preventing the pin **132** from being lifted.

The shutter **66** has an extending pin **150** which engages through an inner race of a needle bearing **152** which rotatably supports the outer end of the

shutter end **66** to the knob **78**. The bearing portion of shutter **66** is notched to connect with a ball and spring detent assembly **154** to a housing portion **156** to provide positioning in the calibrate position. A limit switch **158** is engaged by a groove in the shutter when the shutter is in the calibration position to provide a positive electrical indication thereof.

In order to replace the line source **60**, a plug **160** is removed from the line source holder **62**. The plug **160** has a keyed end **162** which is adapted to receive a uniquely configured key member. In this manner, access to the radioactive line source is denied to other than a designated key operator.

The radiation line source **60** is preferably filled with a radioisotope that has a half-life, between 6 hrs and 300 days. Because this half-life is much shorter than the life of a SPECT camera, the line source must be accessible to be replaced from time to time.

With reference again to FIGURES 3 and 4, the collimator means **42** includes a pair of lead side walls **200** which diverge at an angle which enables transmission radiation to span the examination region **12**. A plurality of thin septa **202** are mounted between the side walls **200**. The septa **202** are constructed of a material which has good radiation stopping power and which, when struck by radiation, emits a gamma ray of relatively low energy, e.g. below 50 keV. Preferably, the septa are constructed of tin or an alloy of tin and antimony. Tin emits gamma rays with a characteristic energy of about 30 keV. Other suitable materials for the septa include metals with an atomic number of about 30-70, particularly tin, antimony, zirconium, niobium, molybdenum, germanium, yttrium, cerium, gadolinium, terbium, dysprosium, holmium, erbium, ruthenium, rhodium, palladium, silver, cadmium, indium, tellurium, cesium, barium, and alloys thereof. Of these, tin, antimony, molybdenum, zirconium, and cadmium are preferred for their more ready availability. The side walls of the collimator **200** could also be made of such materials. However, because many scans call for placing the detector heads as closely adjacent as possible, the transmission radiation source and collimator preferably have as narrow a profile as possible. To this end, the greater stopping power of lead, or other high atomic number material, which permits the side walls **200** to be thinner is preferred. It will be noted that the surface area of the septa which are exposed to radiation from the line source is many times greater than the surface area of the side walls. Optionally, the side walls may be covered or plated on their exposed inside surfaces with tin or one of the other above-discussed metals to limit the emission of the 88 keV characteristic x-rays of lead.

A filter **210** extends across an outlet aperture of the collimator **42**. Th filter includes an inner layer **212** of a material which stops substantially all of the 88 keV energy x-rays from the lead in the side walls of the collimator, yet passes a substantial portion of the radiation fr m the transmission line source **60**. The filter **210** further includes an outer layer **214** which stops substantially all of the lower energy radiation emitted by the inner layer **212** and by the septa **202**. In the preferred embodiment in which the septa are tin or tin/antimony alloy, the inner layer **212** is also tin or tin/antimony and the outer layer **214** is aluminum. The aluminum not only absorbs gamma rays in the 30 keV range, but provide structural strength to the softer tin. Of course, the same alternate metals which can be used to construct the septa can also be used for the inner filter.

Further to the preferred embodiment, the housing has overhanging portions **220** which define a filter receiving track therebetween. A family of filters are provided. The family of filters have varying thicknesses of the inner layer **212**. For example, the inner layer **212** in one of the filters may be of an appropriate thickness to absorb about half of the transmission radiation from the radiation source **60**. Another of the filters might have a thinner tin portion such that only about 1/4 of the radiation is absorbed. Another one might only absorb 1/10 of the radiation, and so on. As the radiation source decays, the filters are replaced with filters which attenuate a progressively small r percent of the radiation. In this manner, the output from the transmission line source assembly can b kept substantially constant over two or more half-lives of the radioisotope in the transmission radiation source. A projection **222** and matching detent **224** in the filters act to snap the filters into position against the natural resiliency of the filter metal. For simplicity of construction and for an assured secure fit, it is preferred that all filters of the family have the same thickness, at least adjacent the edges. Thus, as the tin or more radiation attenuative layer becomes thinner, th aluminum layer becomes thicker.

The invention has been described with reference to the preferred embodiment. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

Claims

1. A nuclear camera system which includes a transmission radiation source (60) which allows primary radiation of a characteristic energy to be transmitted toward a subject, and a collimator (42) for collimating the primary radiation transmitted by the radiation source (60), at least one of the radiation source (60) and collimator (42) tending to emit secondary radiation in response to incident radiation from the radiation source

(60), characterised in that the system includes means for limiting the effect of the secondary radiation on images produced by the system.

2. A camera assembly as set forth in Claim 1 wherein the secondary radiation limiting means comprises material on at least surfaces (200) of the collimator (42), which emits secondary radiation of an energy level that is significantly lower than that of radiation utilised for imaging by the camera system.

3. A camera system as set forth in Claim 2 wherein the collimator (42) includes a plurality of thin septa (202) of said material.

4. A camera system as set forth in any preceding claim wherein the secondary radiation limiting means comprises a filter (210) disposed between the collimator (42) and the subject incorporating a material (212) for preferentially absorbing the secondary radiation.

5. A camera system as set forth in Claim 4 wherein the filter (210) includes a material (212) that absorbs the secondary radiation and reduces the intensity of the transmitted primary radiation and further including a plurality of such filters (210) of different thickness such that as the radiation source (60) diminishes in strength, progressively thinner filters (210) may be substituted to maintain the radiation strength in the subject more nearly constant.

6. A camera system as set forth in any one of Claims 2 to 5 wherein said material is selected from the group consisting of: tin, antimony, zirconium, niobium, molybdenum, germanium, yttrium, cerium, gadolinium, terbium, dysprosium, holmium, erbium, ruthenium, rhodium, palladium, silver, cadmium, indium, tellurium, cesium, barium, and alloys thereof.

7. A camera system as set forth in any one of Claims 2 to Claim 5 wherein said material comprises tin, antimony, or an alloy thereof.

8. A camera system as set forth in any preceding claim further including a shutter (66) for selectively allowing and preventing primary radiation from said source (60) to be transmitted towards the subj ct.

9. A camera system as set forth in Claim 8 further including a connecting means (84, 86) for selectively connecting the radiation source (60), shutter (66), and collimator (42) to the rest of the camera system and a safety interlock (80) which locks the shutter (66) in a closed position when the radiation source (60), shutter (66) and collimator (42) assembly is removed from the rest of the camera system.

10. A camera system as set forth in Claim 9 wherein the safety interlock (80) locks the radiation source (60), shutter (66), and collimator (42) assembly against removal from the rest of the camera system when the shutter (66) is not closed.

11. A camera system as set forth in any preceding claim wherein the camera system produces an image from radiation emitted by a radiopharmaceutical material injected into the subject and the transmission radiation source (60) radiation is used to provide data for correction for radiation lost to scattering or attenuation in the subject.

12. A method of diagnostic imaging in which a subject is injected with a radiopharmaceutical having a first characteristic energy and in which radiation from a transmission radiation source (60) having a second characteristic energy is transmitted from the transmission radiation source (60) through a collimator (42), through the subject, and to a detector head (10), part of the radiation from the radiation source (60) striking internal surfaces of the transmission radiation source (60) and/or collimator (42) causing the emission of secondary radiation, characterized by: limiting the secondary radiation passing through the subject.

13. A method as set forth in Claim 12 wherein th secondary radiation limiting step comprises preferentially absorbing the secondary radiation.

14. A method as set forth in Claim 13 comprising attenuating the transmitted radiation with a filt r (210) that also preferentially absorbs the secondary radiation, and, as the radiation source (60) ages, replacing the filter (210) with a filter (210) giving reduced attenuation of the transmitted radiation such that the radiation strength in the subject is more nearly constant over time.

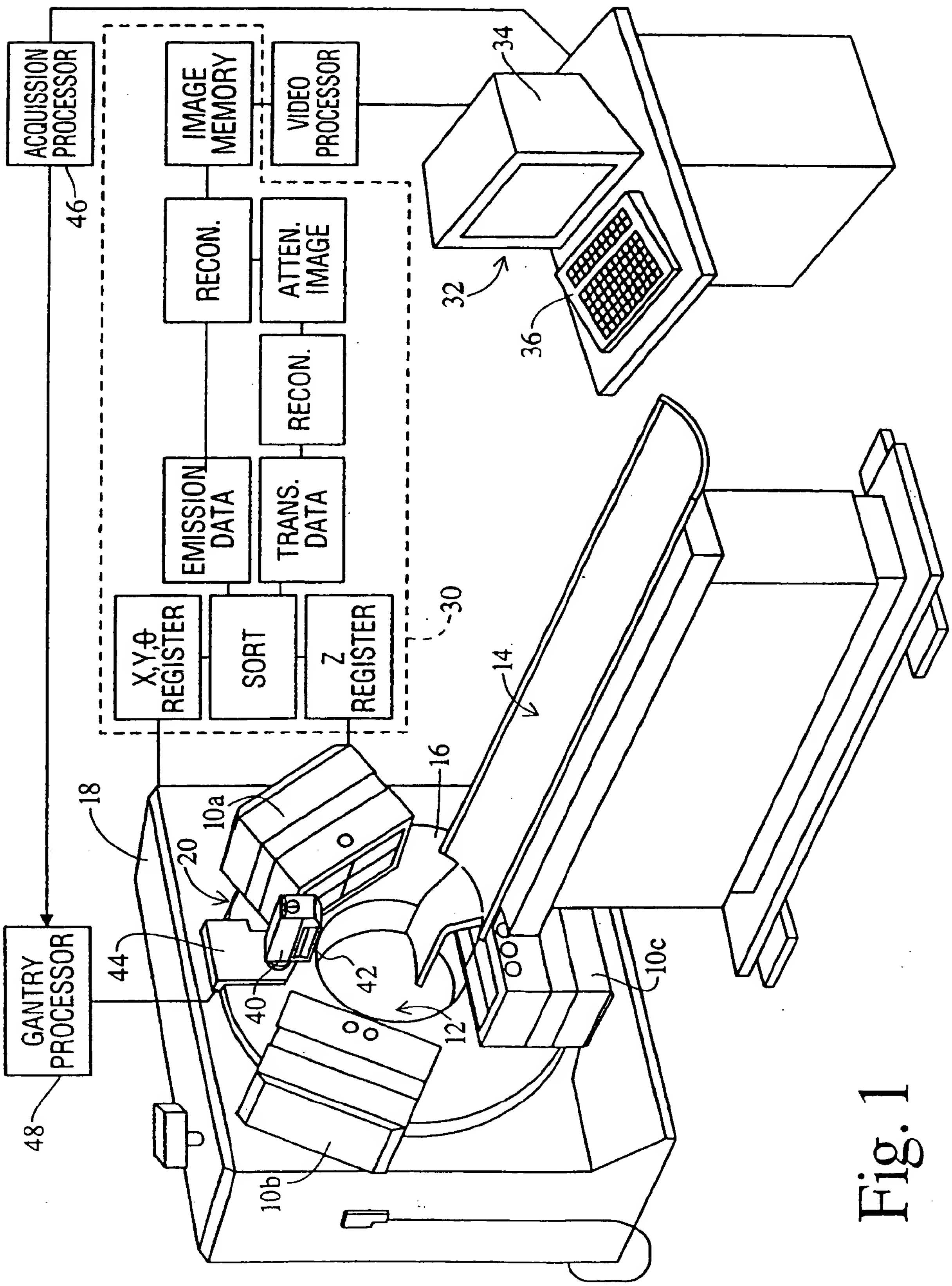
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Fig. 1

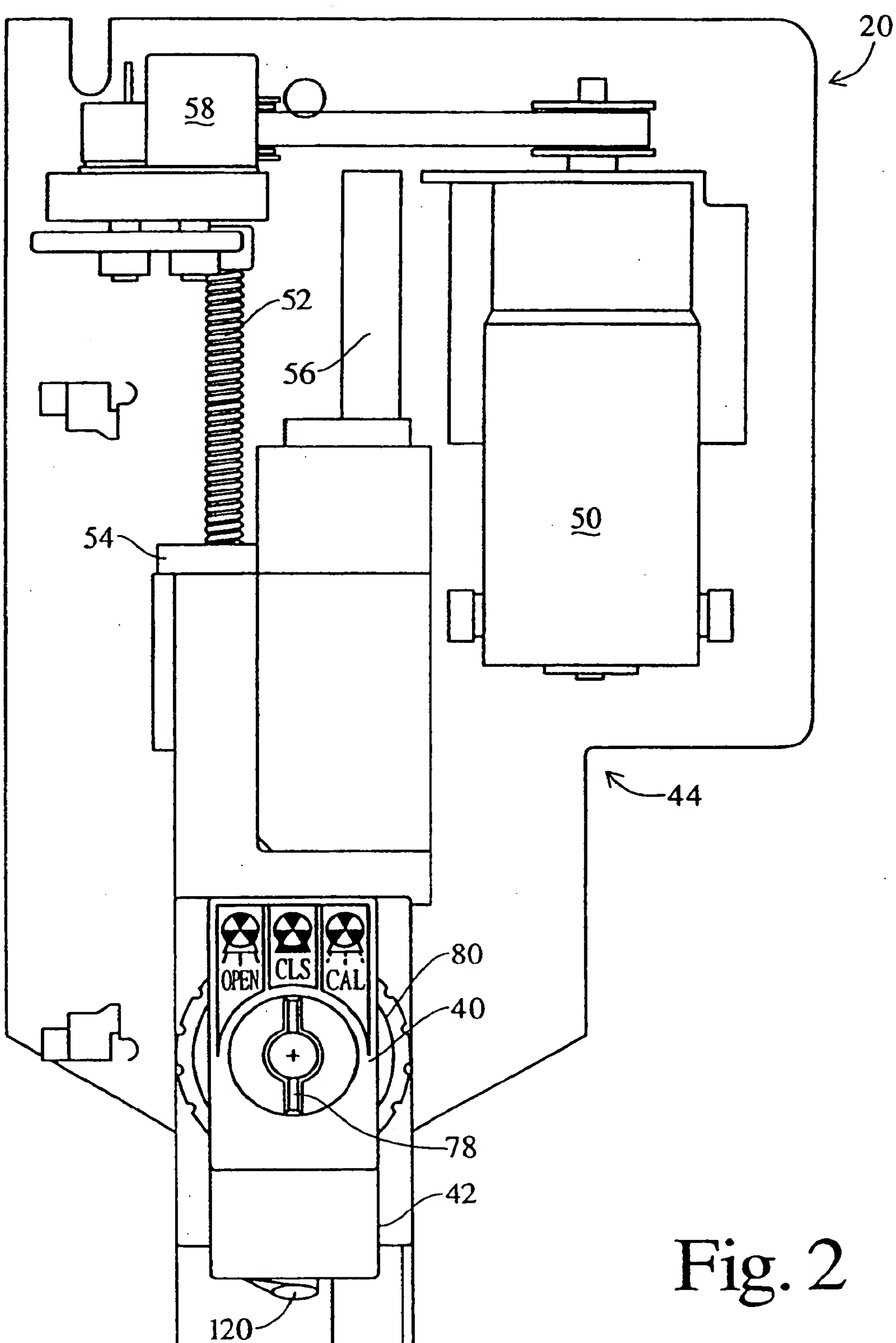

Fig. 2

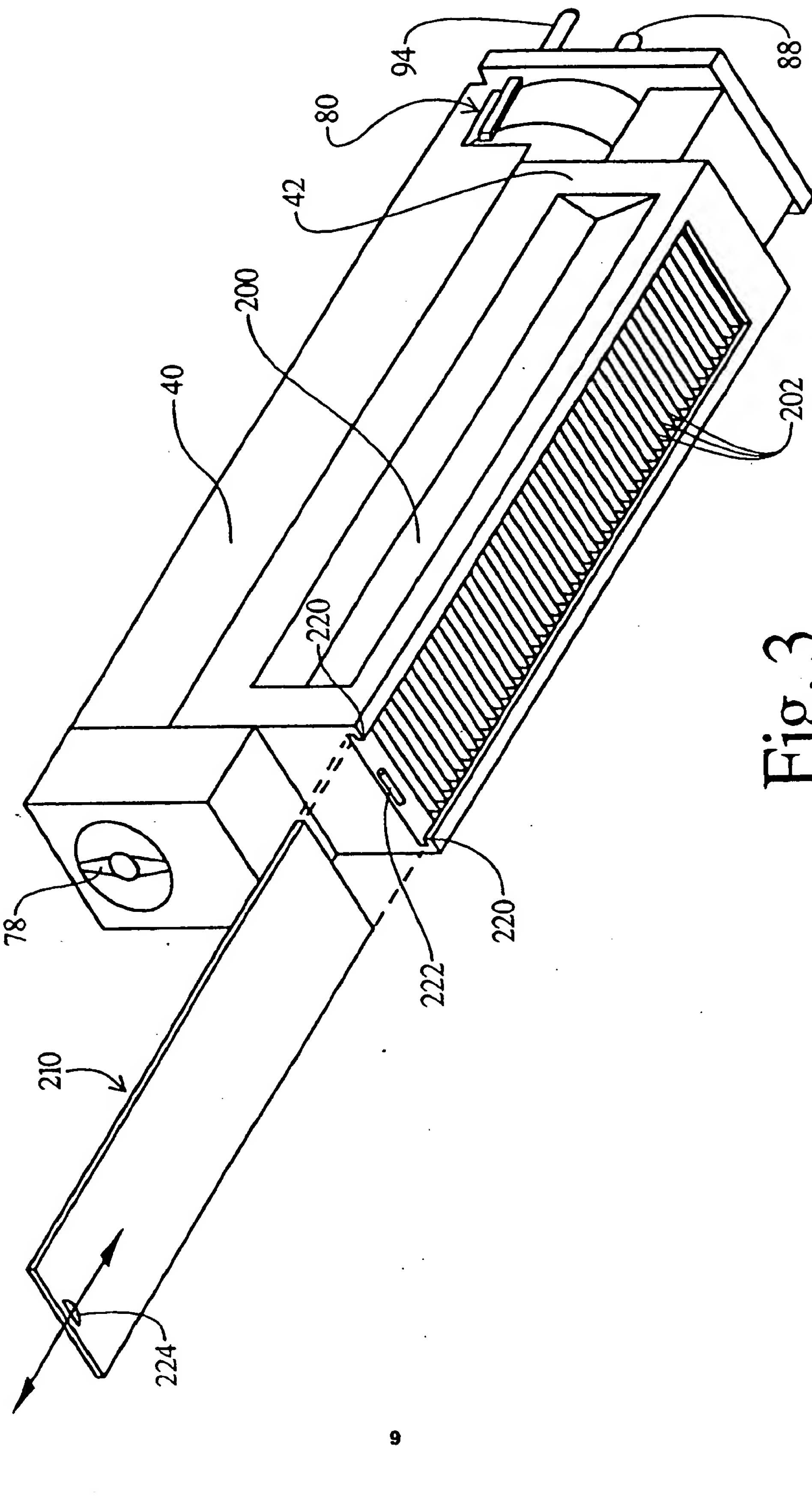

Fig. 3

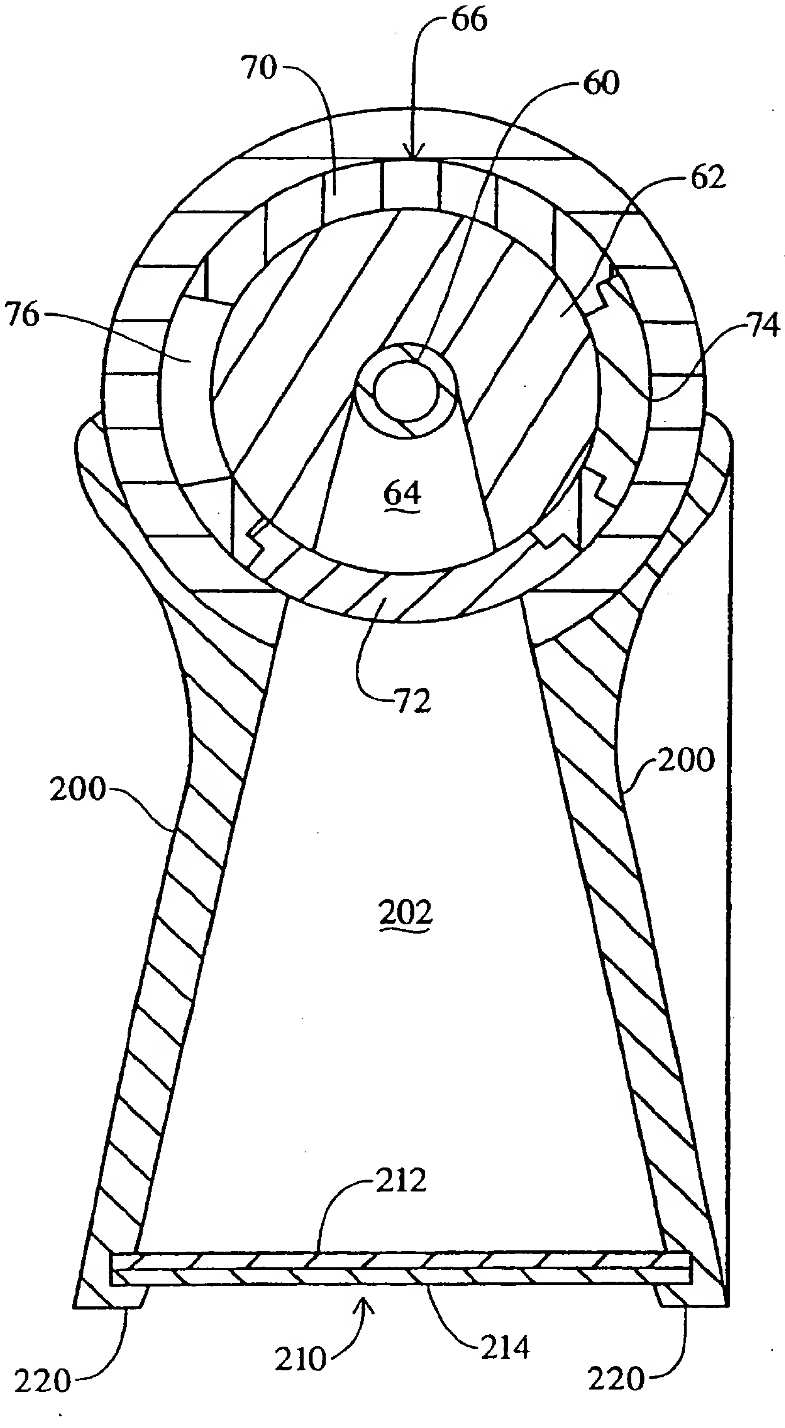

Fig. 4

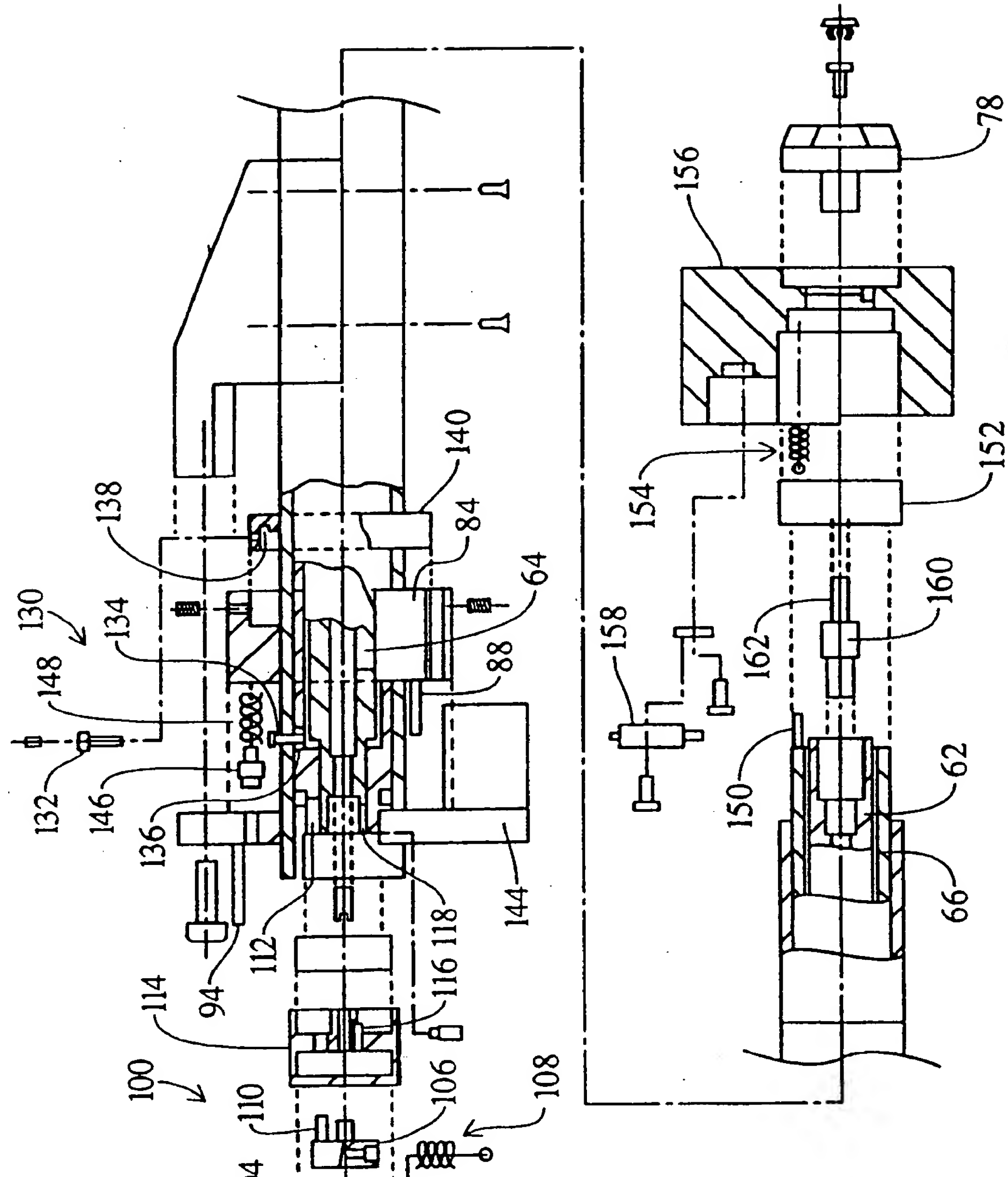
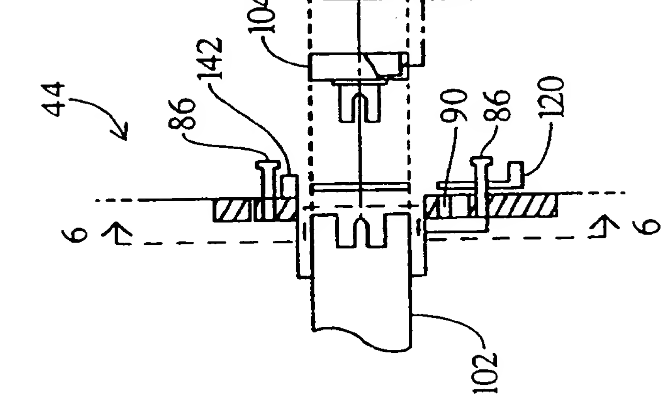
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Fig. 5

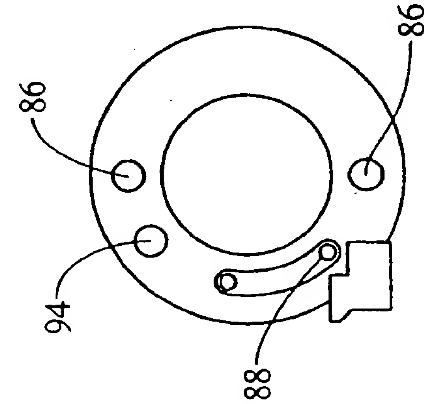
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Fig. 6